

LSSCS BAA Topic 2: Minimum Functionality Habitation Element

US Chamber of Commerce
Lunar Surface Systems Workshop

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Boeing Study Team Participants

- Andrew Daga & Associates
- American Aerospace Advisors
- Hamilton Sundstrand
- Harris
- Honeywell
- ILC Dover
- Lunar Transportation Systems
- Oceaneering
- Orion Propulsion
- SICSA
- Thin Red Line
- USA



Andrew Daga & Associates
SPACE TECHNOLOGY CONSULTANTS



Honeywell

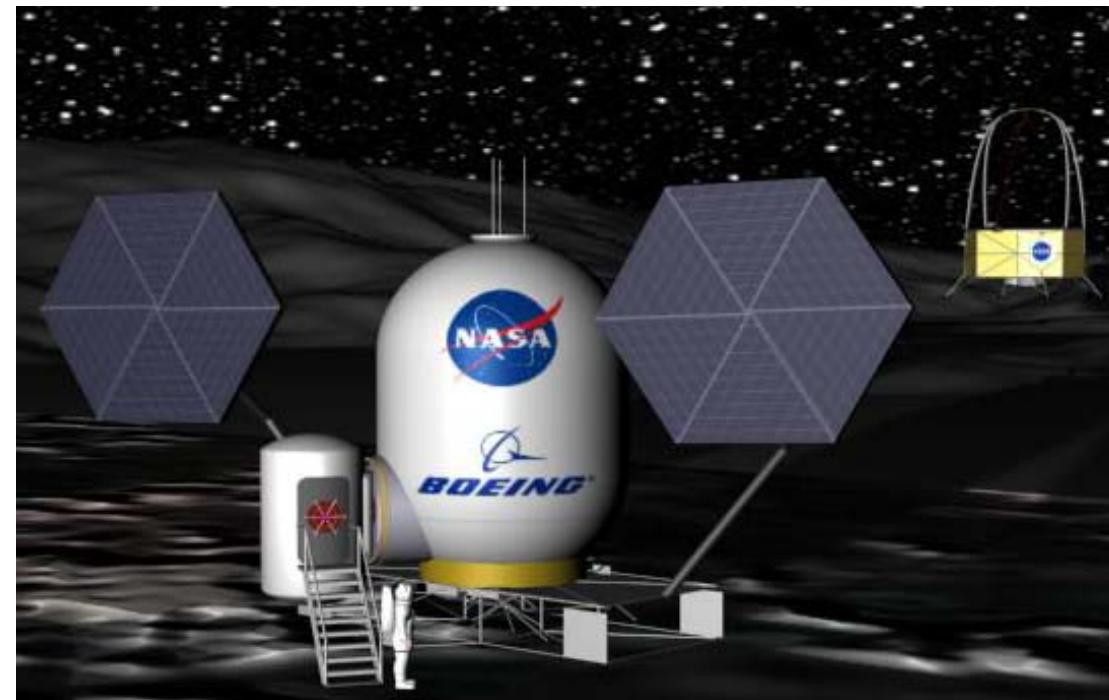


LSSCA BAA Topic 2: MFHE Definition

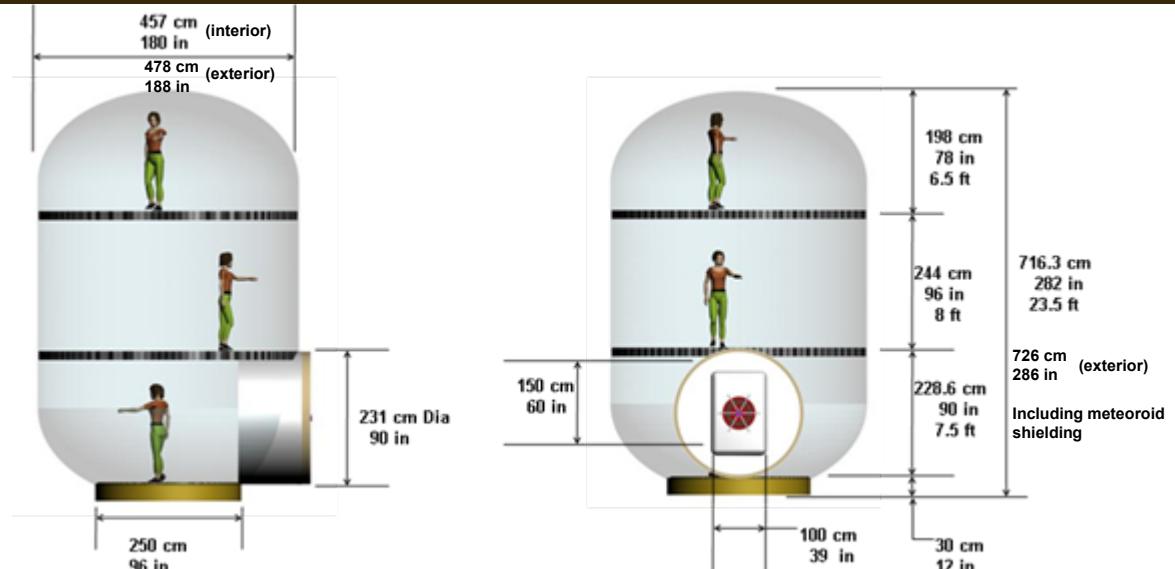
- Minimum Functionality Habitation Element

- Deployable Habitat

- The Path to Growth

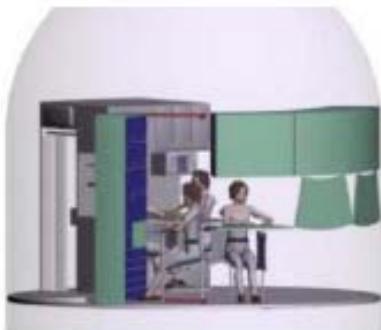


Boeing Integrated MFHE Concept PILL - Pressurized Interim Lunar Lodge



- One primary and two ancillary floors
- 78 m³ habitable of 121 m³ total pressurized volume
- 28 m² open of 35 m² total floor area
- 457 cm (15 ft) diameter with 228.5 cm (7.5 ft) ceiling
- Entry foyer on lowest floor; Sleeping on upper floor

MFHE Living Space Arrangements



- **Four work stations**

- Medical / Life Sciences
- Mission and habitat operations
- Physical sciences with glove box
- Generic work desk

- **Food management and storage**

- **Hygiene module**

- **Toilet**

- **Foldable dining / conference table**

- **Access to lower & upper floors**



Summary MFHE Characteristics (28 day Mission + 30 day Contingency)

Description	Mass (kg)	Internal Volume (m ³)	External Volume (m ³)	Peak Power (kW)	Average Power (kW)	Heat Rejection (kW)
Structure and Atmosphere	3697					0.04
Subsystems, Workstations, Hygiene and Commode	661	8.0	0.06	2.3	1.5	3.04
Logistics Pallet and Consumables	899	0.3	2.28	0.3	0.3	
Growth	499	3.4	0.0	1.3	0.9	1.52
Flight Support Equipment	288					
Total	6044	11.7	2.34	3.9	2.7	4.60

- Internal volume for subsystem components
 - Required, with 25% packing factor 0.8 m³
 - Available in lower dome 17.1 m³
- Internal area for subsystem components
 - Required, with 25% packing factor 24.5 m²
 - Available in lower dome (1 layer on shell) 27.4 m²

Growth allowance: mass, structure - 15%; mass, components - 50%; power & heat rejection - 50%; packing factor - 25%

MFHE BAA Requirements

- Basic safety features without contingencies protection
- Define minimum required functions for reference mission support
- Provide conceptual design incorporating minimum functions
- Provide MFHE mass, power and volume estimates
- Define potential growth options from MFHE
- Total mass limited to 7000 kg
- Support 4-person crew for 28 days with 30-day contingency
- Fit within 8.8 m dia and 17.2 m tall Ares V shroud
- Provide 8 psi atmosphere with 30% oxygen and 70% nitrogen
- Provide hab health status upon arrival and before crew launch
- Support science and exploration objectives with regular EVAs

18 Functions Identified and Allocated to MFHE

- Atmosphere Management
- Communications
- Crew Accommodations
- Data Management / C&DH
- Dust Mitigation
- Electricity Distribution
- Food Management
- Hab Health Monitoring
- Health Mgmt (First Aid Kit)
- Hygiene Management
- Intermodule Connectivity
- Meteoroid Protection
- Radiation Protection
- Stowage
- Thermal Management
- Waste Management
- Water Management
- Work Accommodations

18 MFHE Functions Allocated to 9 Subsystems

- Avionics
- Dust Mitigation
- ECLSS
- Flight Crew Systems
- Mission Payloads
- Electrical Distribution System
- Structure & Mechanisms
- Thermal Control System
- Trash Management

Derived MFHE Size Driving Requirements

● Ares V payload envelope constraint (m)	8.8 x 17
● Minimum free volume (28 day, 4 people) (m ³)	37.0
● Occupied volume (m ³)	7.2
● Linear wall space (m)	5.4
● Floor space - unique (m ²)	3.2
● Shared floor space (m ²)	5.0
● Internal storage (m ³)	1.0
● 30-day radiation dose limit from major SPE (cSv)	25

Habitat Structure

- Upright Aluminum cylinder with radical 2 domes
- 716.3 cm (23.5 ft) total internal height
- 228.6 cm (7.5 ft) hab internal radius
- 15.24 cm (6 in) floor thickness for utility runs
- Aluminum honeycomb panels for interior structure
- 228.6 cm (7.5 ft) cylindrical entryway / intermodule connector
- Hatch characteristics from ISS hatches
- Intermodule Connector based on ISS ACBM

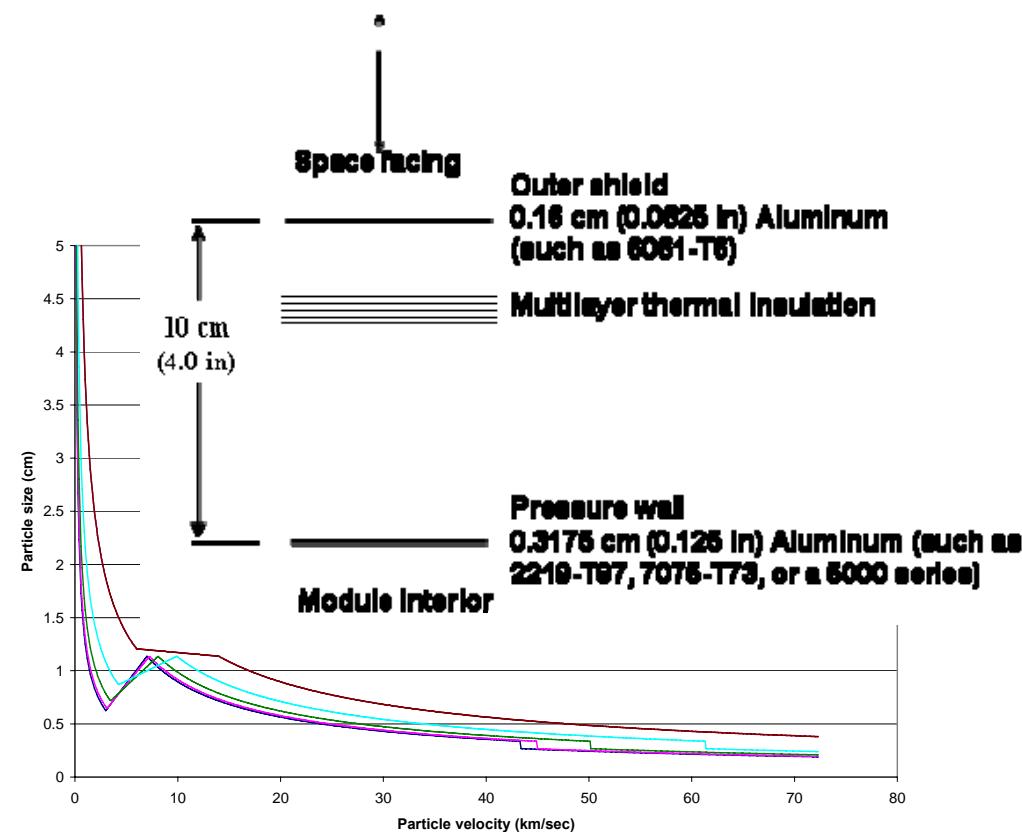
Intermodule Connector Assembly

- 228.6 cm (7.5 ft) cylindrical entryway / intermodule connector
- Intermodule Connector based on ISS ACBM
- Hatch characteristics from ISS hatches



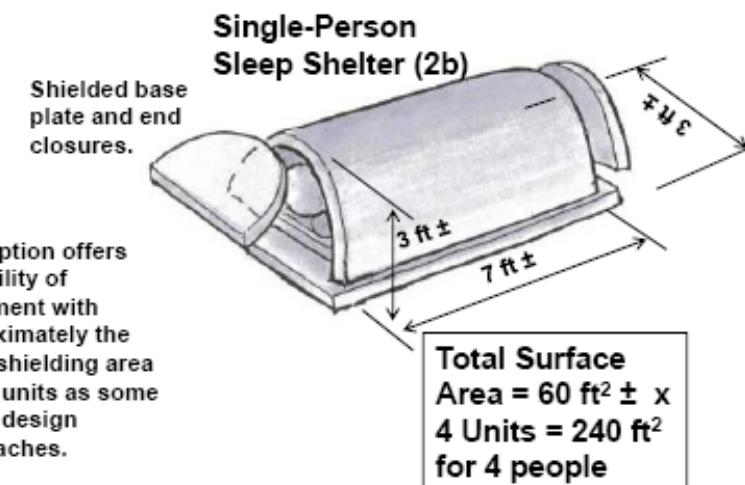
MFHE Radiation and Meteoroid Protection

1.2 cm D Meteoroid Protection



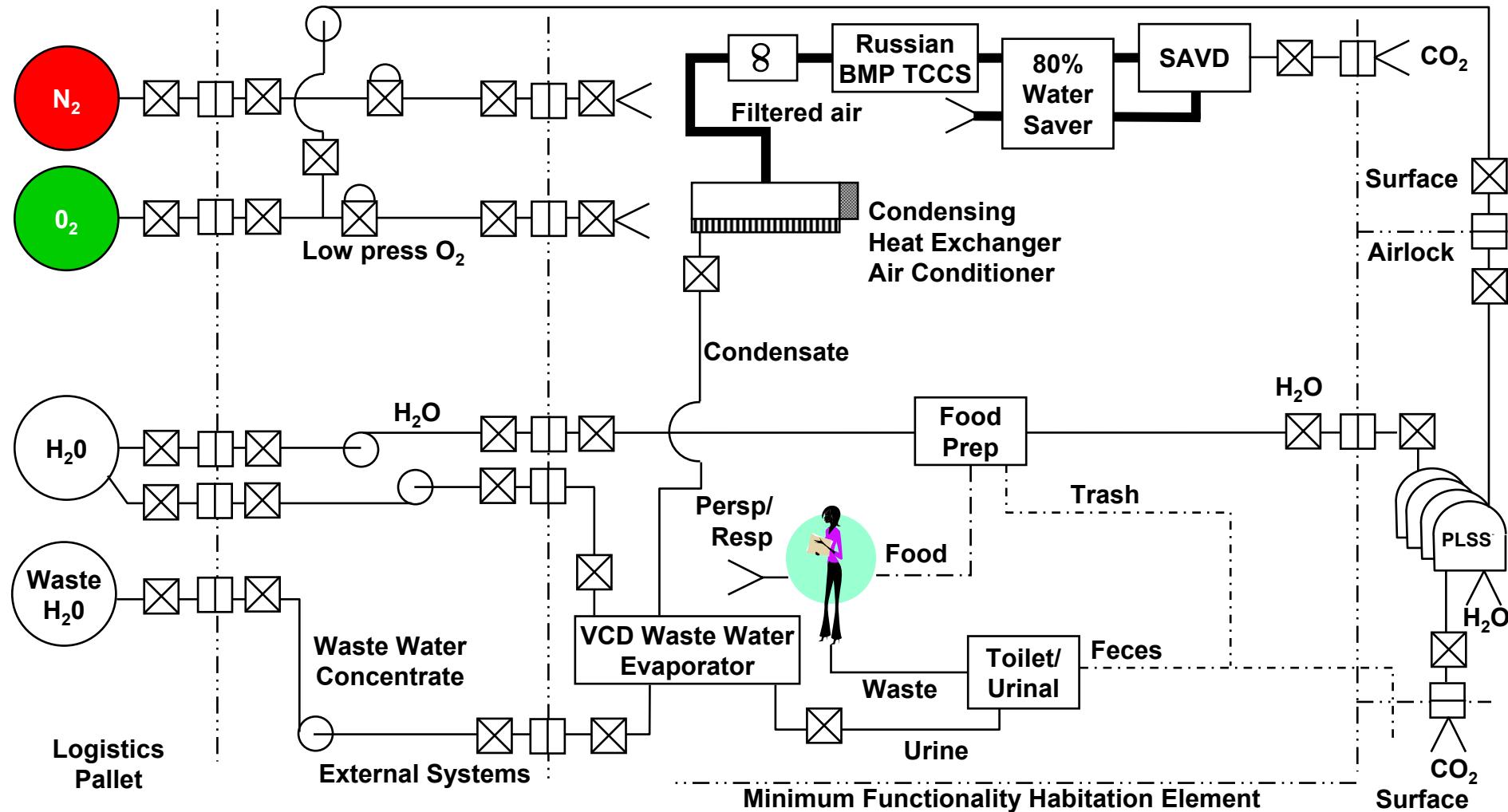
0.16 cm Al Whipple plate provides 0.9997 PNP/yr

Major Solar Proton Event Protection

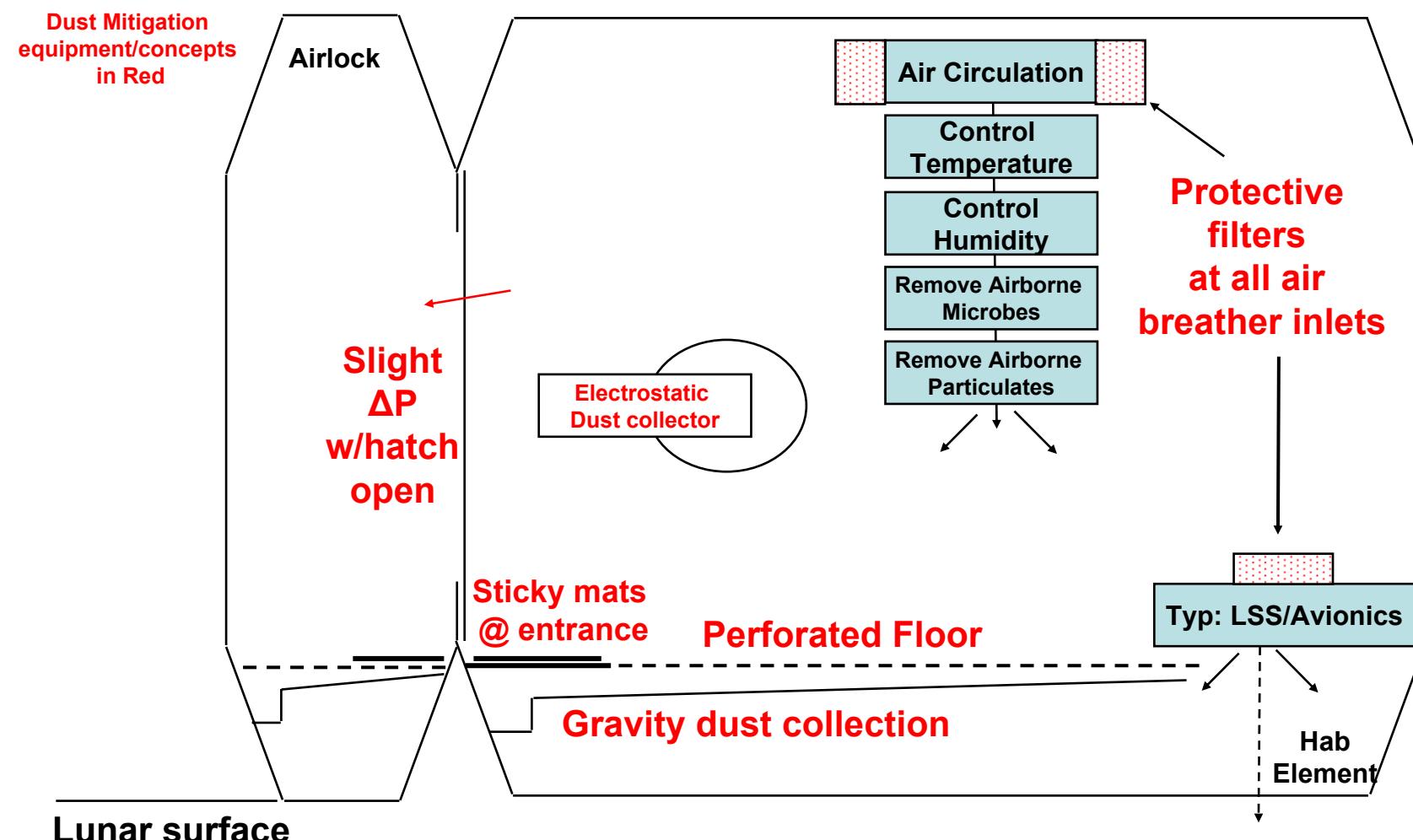


10 cm polyethylene pup tent for SPE radiation protection

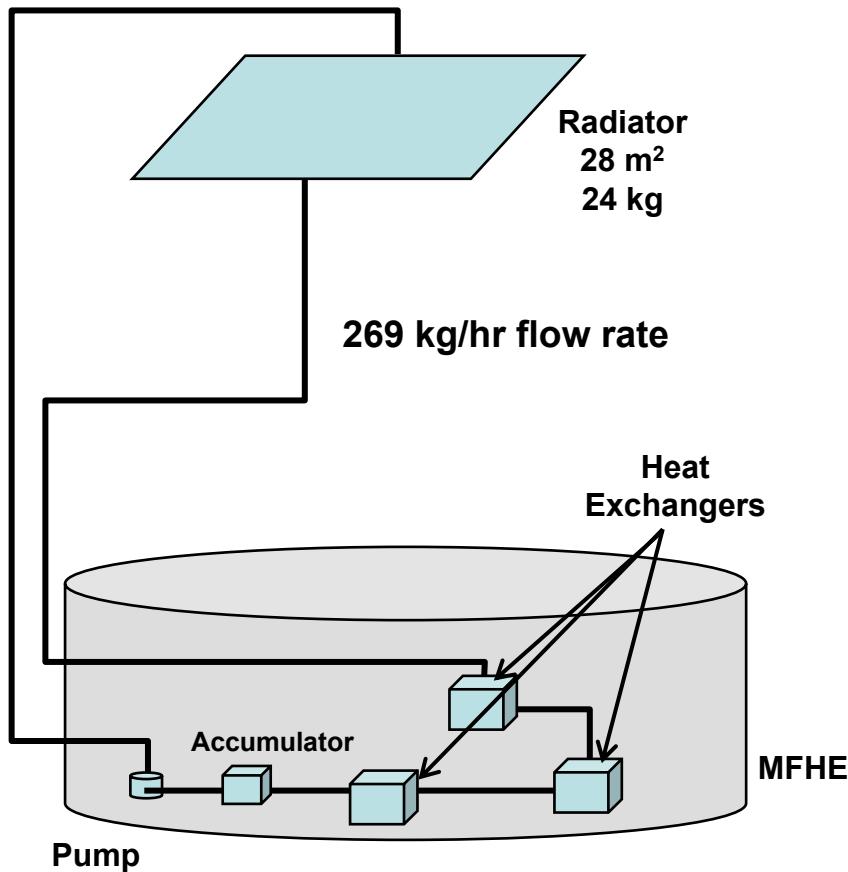
Water Recovery is a Key ECLSS Capability



MFHE Dust Mitigation Incorporated in ECLSS, Air Flow and Hab Layout



Single-Loop Single-Fluid Thermal Control System



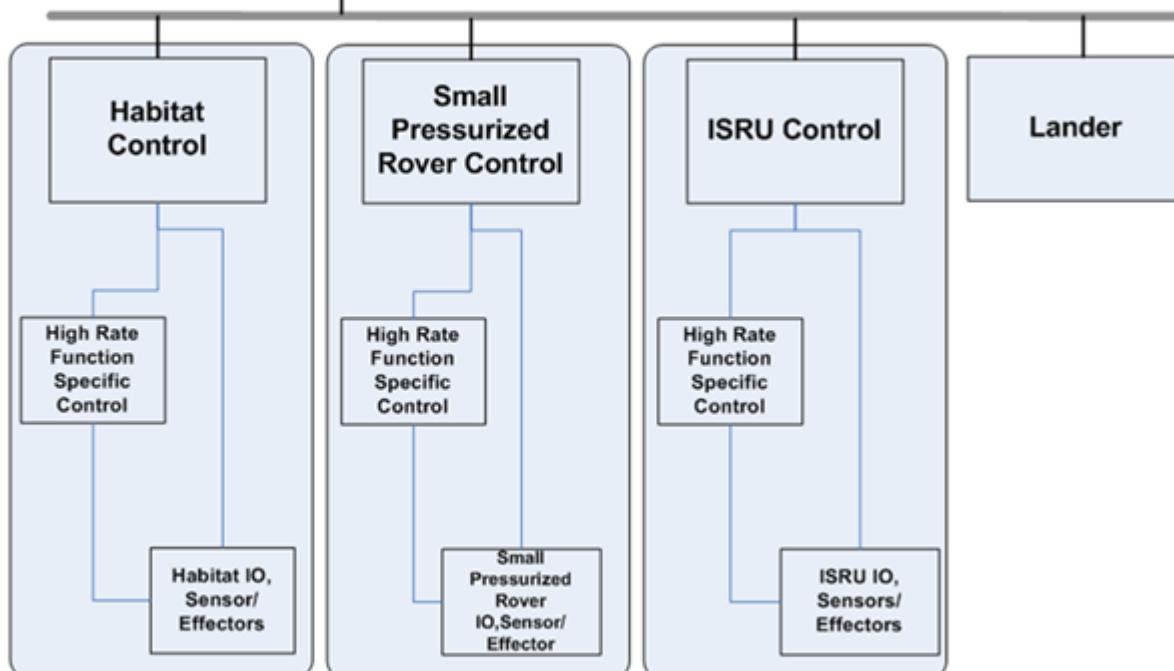
- Simple flat-plate aluminum radiator
- Assumed 20 gal coolant volume
- 3M Novec HFE-7200 coolant
- Air to coolant heat exchangers
- Cold plates for electronics
- 4554 kW heat rejection capacity

HI LSS Study Elements with Level Allocation - MFHE Avionics within LSS Architecture Concept

- Level 3
- Production Mgmt
 - Maintenance Mgmt
 - Resource Mgmt



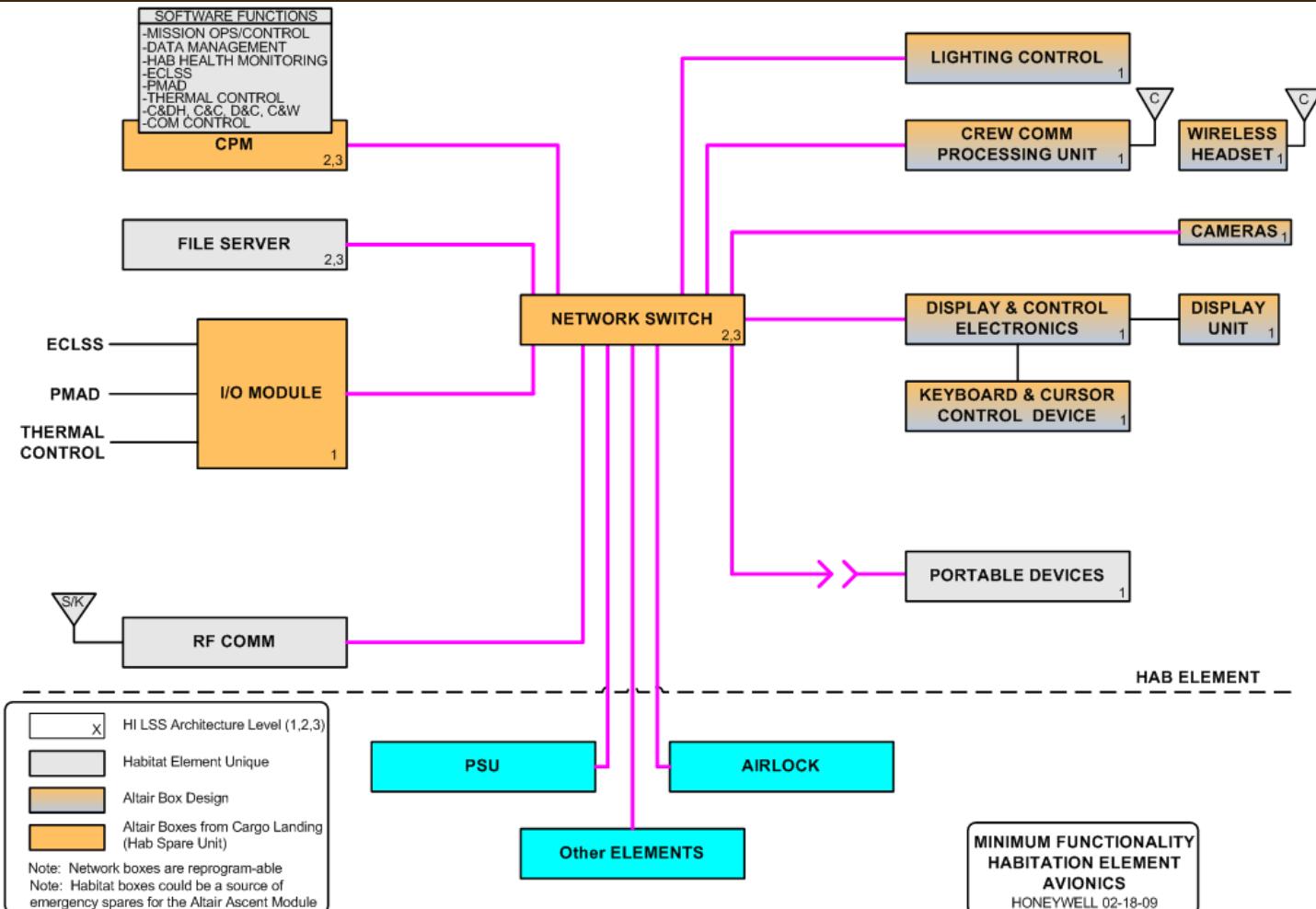
- Level 2
Vehicle Control
- Sequencing
 - Directing
 - Coordinating
- Health Status



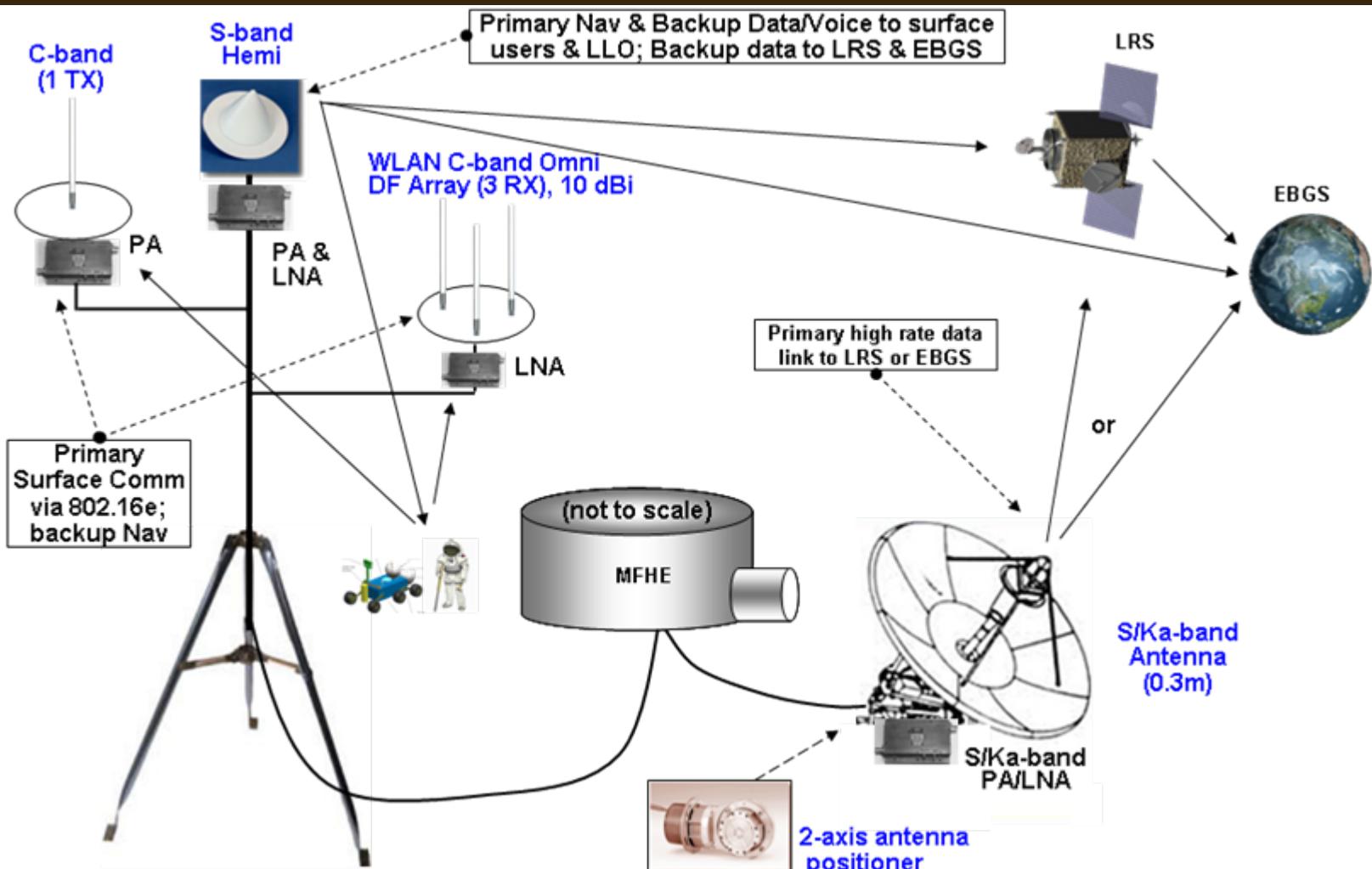
- Level 1
- High Rate Control
 - Standard IO/
Power Control
 - Standard Sensor/
Effectors

Enabled by standard functionality at each level with
communications enabled by data standards

Minimum Habitat Avionics Architecture



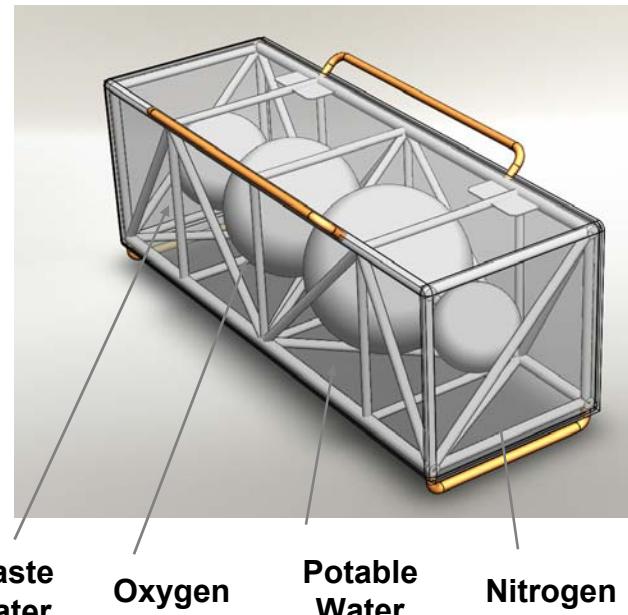
MFHE Communications Overview



MFHE Logistics Support

- 28-day stay plus 30-day contingency
- Flex lines for MFHE connection
- Four Consumables (kg) 474
 - Oxygen: 196
 - Potable Water: 262
 - Nitrogen: 16
 - Waste Water (capacity 69 kg): 0
- Hardware mass (kg) 296
- New pallet required for each mission
- Food (carried separately) (kg) 129

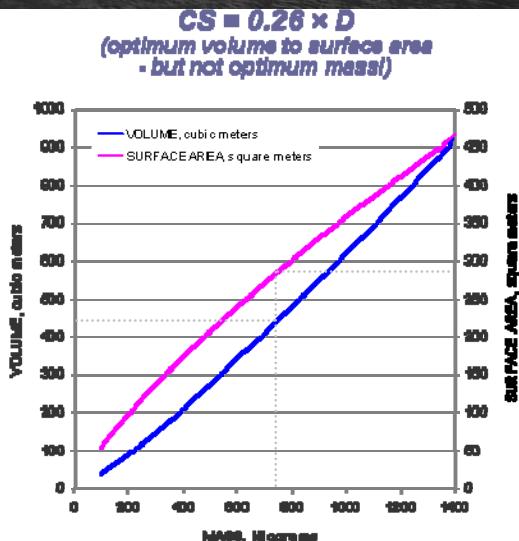
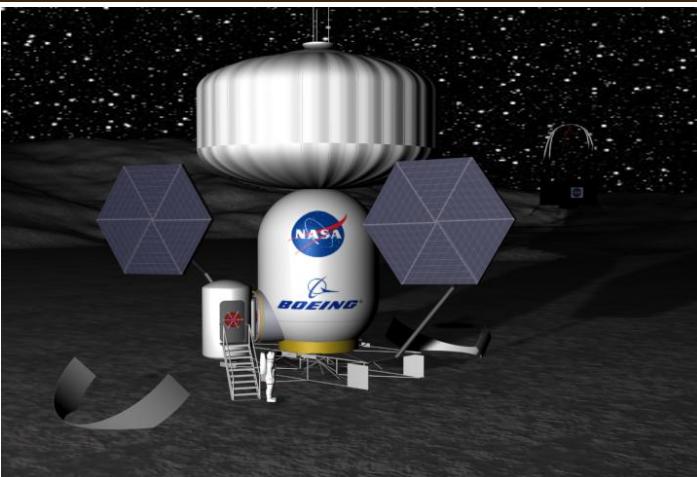
899 kg including food in Hab



Deployable Habitat Derived from MFHE

- Added two access ports and hatches to ingress floor
- Fire detection, suppression, and remediation
 - Hand-held fire extinguishers
 - Atmosphere replacement capability
- Emergency breathing apparatus, Personal Protection Equipment
- Identified FDIR need (software, Avionics, etc.)
- Added redundancy and spares to Avionics, Comm, ECLSS, & TCS
- Exercise equipment added
- Provided external viewing capability via HD cameras and monitors
- Increased heat rejection capacity
- Included habitat tool kit
- Added one hatch to top dome to accommodate growth

Deployable Concept with Inflatable Upper Room



- Delivered deflated and protected
- Additional atmosphere on logistics pallet
- Can be delivered with Hab or Cargo
- Can be expanded during any crew mission
- Inflatable element characteristics

• Structure (kg):	700
• Atmosphere (kg):	312
• Volume (m³):	439
• Floor area (m²):	120
• Surface area (m²):	290
• Diameter (cm):	914
• Constant diameter height (cm):	238

Summary Deployable Hab Characteristics (28 day Mission + 30 day Contingency)

Description	Mass (kg)	Internal Volume (m ³)	External Volume (m ³)	Peak Power (kW)	Average Power (kW)	Heat Rejection (kW)
Structure and Atmosphere	5089					0.04
Subsystems, Workstations, Hygiene and Commode	1132	8.8	0.07	3.2	2.2	3.42
Logistics Pallet and Consumables	1003	0.3	2.28	0.3	0.3	
Growth	741	5.7	0.0	1.7	1.2	1.71
Flight Support Equipment	402					
Total	8445	14.5	2.35	5.2	3.7	5.17

- Internal volume for subsystem components
 - Required, with 25% packing factor 0.8 m³
 - Available in lower dome 17.1 m³
- Internal area for subsystem components
 - Required, with 25% packing factor 24.5 m²
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Growth: mass, structure - 15%; mass, components - 50%; power & heat rejection - 50%; packing factor - 25%

Opportunities to Meet 7000 kg Constraint for Deployable Habitation Element

- 741 kg Growth Allowance reassessment (247)
- 1003 kg Logistics Pallet resized for 14-day mission (600)
- 2230 kg radiation protection mass reduction opportunities (1115)
 - Resize for 14-day missions per Scenario 4.0.0
 - Include structure and internal outfitting for radiation protection
 - Use Entry Foyer instead of Sleep Loft to eliminate “pup tent” floor
 - Install regolith layer around lower dome
- 1632 kg CBM and hatch reduction opportunities (544)
 - Redesign ISS ACBM and hatch for 8 psi operating pressure vs 14.7
 - Redesign ISS ACBM for expected lunar surface loads environment
- Potential reduction (1450 target) (2306)

Habitation Growth Path - 1

● Mission 6 - Cargo (Unpressurized Payload)

- Inflatable Module + connector & hatch 1158 kg
- Atmosphere Pallet for Inflatable Module ~800 kg

Boeing
Additional
Growth
Items

● Mission 9 - Cargo (RPLM-1)

- Additional volume attached to Deployable Hab port #3 55 m³
- Four private sleep stations
- Urgent Care capability with minor dental hygiene (Telemedicine)
- ECLSS, TCS, electrical power distribution
- CO₂ reduction to carbon using methane pyrolysis
- Water electrolysis
 - Hydrogen production for CO₂ reduction
 - Oxygen production
- Wet food, freezer, refrigerator
- Full galley
- Trash compactor

Matches
Scenario
4.0.0

Boeing
Additional
Growth
Items

Habitation Growth Path - 2

● Mission 12 - Cargo (RPLM-2)

- Additional volume attached to Deployable Hab port #1
- ECLSS, TCS, electrical power distribution
- Surgical and dental capability
- Expanded scientific capabilities (includes 4.0.0 bioscience)
- Shower

55 m³

Matches
Scenario
4.0.0

Boeing
Additional
Growth
Items

● Mission 15 - Cargo (DPLM-1)

- Additional volume attached to Deployable Hab port #2
- TCS, electrical power distribution
- ECLSS
- Clothes washer
- Dishwasher

55 m³

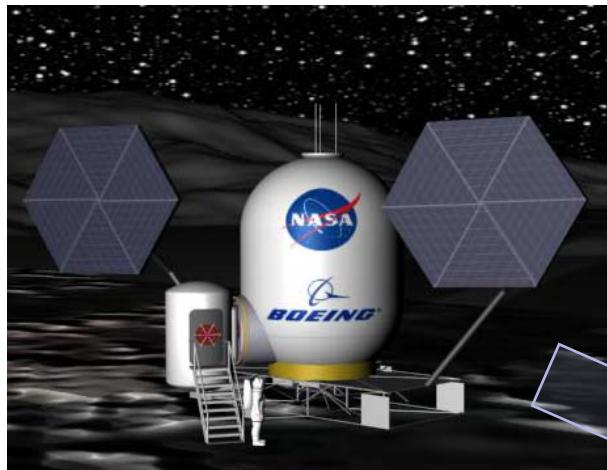
Matches
Scenario
4.0.0

Boeing
Additional
Growth
Items

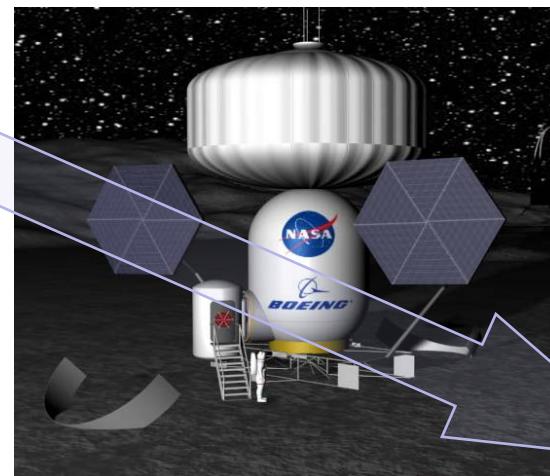
● Beyond Mission 16

- Vegetable garden unit with biochemical life support
- Composting toilet

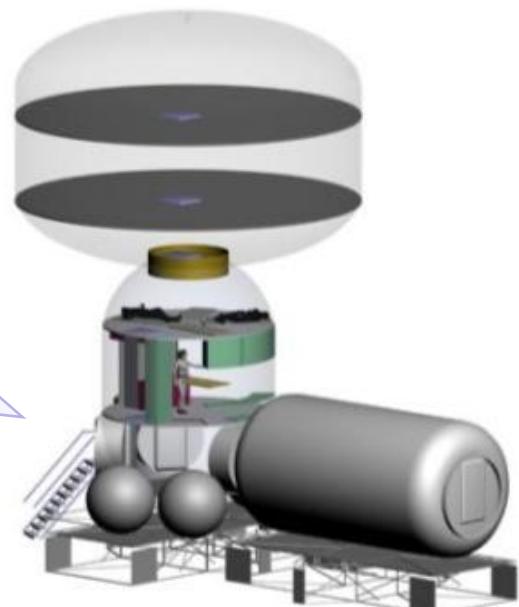
Direct Path From MFHE to Outpost Capability



Mission 5



Mission 7



Mission 10